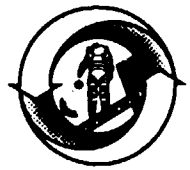
NASA Ames Research Center
Regenerative Life Support Branch



Status of Regenerative Life Support Research and Technology Program at NASA Ames Research Center

Presented at

IES - CELSS International Conference on:

Closed Ecological Systems for Terrestrial and Space Applications

Obuchi, Rokkasho, Aomori 039-32 Japan

July 21-23, 1998

Ames Role in ALS Program

AMES RESEARCH CENTER

- Provide innovative technology concepts and assessments for application to Advanced Life Support Systems for International Space Station, Crewed Transit Vehicles and Lunar and Martian surface habitats, emphasizing system closure and self-sufficiency.

- Research and Technology Development is focused on physicochemical processes for the following life support functions:
  - Air Regeneration
  - Water Recovery
  - Solid Waste Processing/Resource Recovery
  - Systems Modeling and Analysis, and Controls

- Conduct small-scale concept and technology development to provide feasible prototype subsystems at appropriate readiness levels needed for transfer to integrated ground test bed development and evaluation

- Transfer technologies to public and commercial sectors as appropriate

Major Technical Objectives

OBJECTIVES

1. Provide Advanced Life Support technologies that significantly reduce life cycle costs, improve operational performance, promote self-sufficiency, and minimize expenditure of resources for missions of long duration.

2. Develop and apply methods of systems analysis and engineering to guide investments in technology, resolve and integrate competing needs, and guide evolution of advanced life support systems.

3. Resolve issues of hypogravity performance through space flight research and evaluation.

4 Ensure timely transfer of new life support technologies to missions.

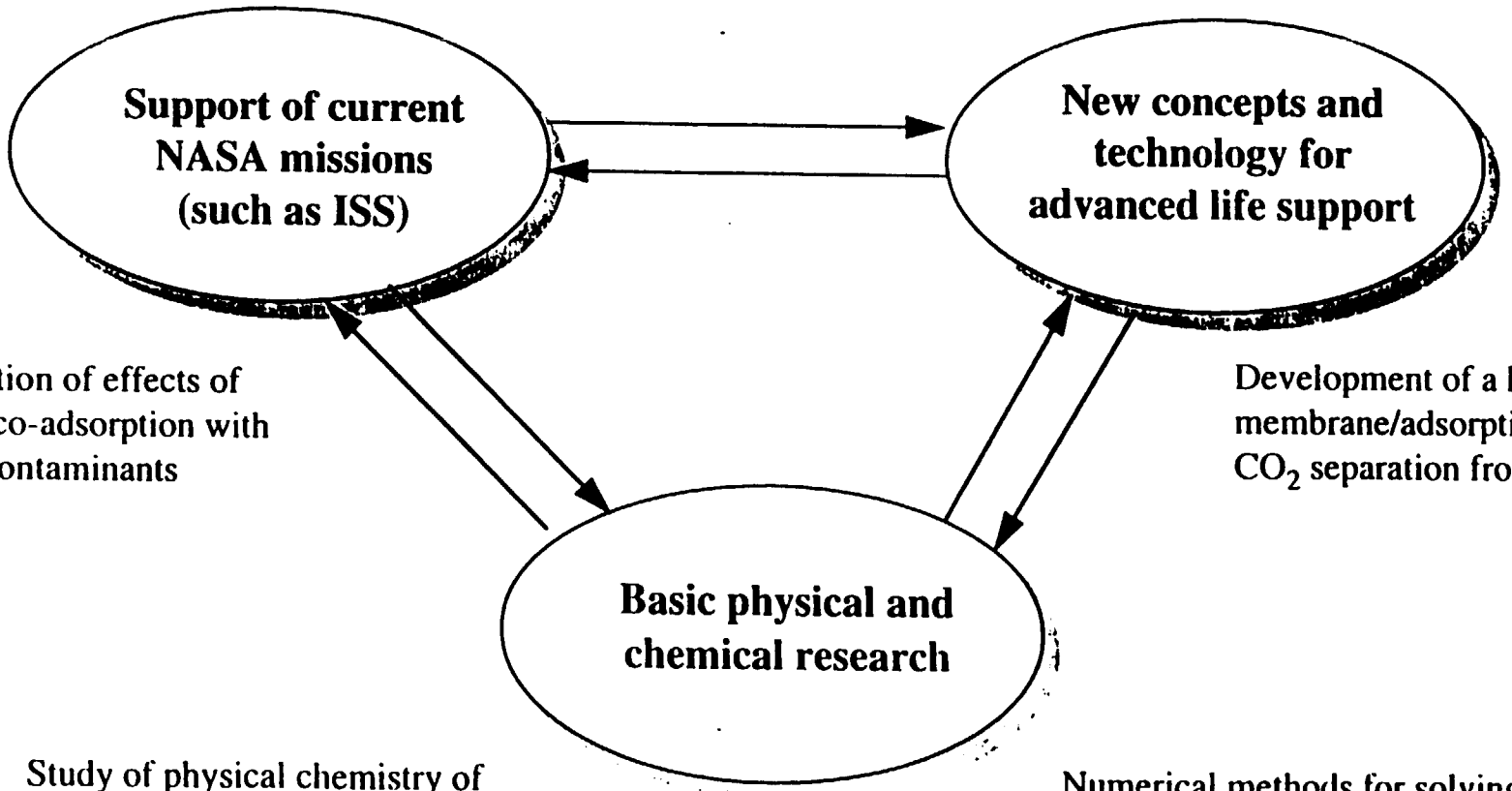
5. Transfer technologies to private sectors for national benefit.

Focused Research Areas

Air Regeneration Research Projects Performed at NASA Ames

Characterization of adsorption in the 4BMS (CO_2 removal for ISS)

Temperature swing adsorption for utilizaiton of Mars atmosphere gases



Prediction of effects of water co-adsorption with trace contaminants

Development of a hybrid membrane/adsorption unit for CO_2 separation from air

Study of physical chemistry of adsorbed CO_2/H_2O solutions

Numerical methods for solving multiple interacting wave propagation problems (adsorption column simulations

Focused Research Areas

Air Regeneration

Some Air Revitalization Needs

Work Being Performed at ARC

- **A lower-power CO_2 removal technology**

  The CO_2 removal units in just the U.S. Hab and Lab modules on ISS will consume about 2% of the power generated for the entire station in order to maintain CO_2 at a level about 10x higher than Earth-normal in those modules

- **Trace contaminant control systems less susceptible to upsets within the habitat**

  On-board humidity swings can result in the release of previously removed contaminants into the process air stream

- **Regenerable trace contaminant control systems**

  Current technology for ISS will require an estimated $3 million/year in resupply costs

- **Technologies that will use resources at the destination (e.g., Mars) for air revitalization**

  In-situ resource utilization technologies are probably mission-enabling, due to savings of Earth launch costs

Additional Research Required

> **Development of advanced carbon dioxide reduction technology**

  Existing technologies for producing elemental carbon from CO_2 are not flight-ready

> **Development of improved gas sensor technology**

  Existing sensors require too-frequent calibration and service

Solid Waste Processing

GOAL

Self-sufficiency in life support for space

Long missions, but little or no food production

Destroy hazardous or noxious wastes

Long missions incorporating biological processors

Reclaim CO_2 and nutrients from waste for biological processors

Promising Solid Waste Processing Technologies

1. **Supercritical water oxidation (SCWO)**
   - Modar Inc. Phase II SBIR completed
2. **Incineration**
   - University of Utah
   - Reaction Engineering Inc. - Phase I SBIR started
   - In-House microwave incinerator
3. **Wet oxidation**
   - University of Tulsa JRI
4. **Electrochemical oxidation**
   - Lynntech Inc. Phase II SBIR completed
5. **Steam reformation**
   - Synthetica Inc. Phase I SBIR completed
6. **Pyrolysis**
7. **Biological waste treatment**

Waste Processing / Utilization

Solid Waste Recovery

OBJECTIVE

- **Evaluate advanced incinerator technology options and develop incinerator for application to EHTI Phase III and Bio-PLEX (Destroy wastes; reclaim CO_2 and nutrients for biological processors)**

STATUS

- **Contract with Utah State University in place**
- **Emphasis shifted from biomass conversion to include human waste**
- **Completed design, fabrication, and feed system development**
- **Testing at Utah with simulated human waste completed**

NEXT

- **Deliver to NASA-ARC**
- **Install O_2, NOx, CO/CO_2, SO_2 instrumentation**
- **Shake down testing with human /Shuttle waste**
- **Analytical characterization of system outputs**
- **Compatibility verification with plants**
- **Deliver to NASA-JSC**

Waste Processing / Utilization

Solid Waste Recovery

OBJECTIVE	• Development of continuous Supercritical Water Oxidation (SCWO) reactor
STATUS	• Demonstrated effectiveness on liquid human waste streams • Focus is currently on development of solid feed system(slurry/pumping) • Phase I SBIR with Umpqua on feed pretreatment using acid hydrolysis
NEXT	• Investigate biological feed pretreatment and other options • Initiate solid waste stream testing

Water Recovery Systems

ARC Wastewater Technology Development Program Rational and Approach

THE SPACE STATION ALPHA CASE (provides a baseline)

- Assuming that it costs $22K (Goldin) to deliver a Kg to a low earth-orbit and that the one year systems resupply requirement for a combined WRS system is 465 Kg (Carrasquillo 96).
- It will cost over $10 million per year to maintain the WRS.

THE FUTURE PLANETARY HABITAT CASE

- For long-range missions, such as Lunar or Mars missions, resupply costs will be an order of magnitude greater. Currently estimated at $105K per Kg (Kaplan 96).

ARC RESEARCH

- Directed at development of the next generation of fully regenerative technologies and enhancements to the baseline (reduce operational costs ISS systems).
- Research and development pursued through a combination of contractor and in-house development.

Focused Research Areas

Water Recovery Systems - Near Term Research

TECHNOLOGY DEVELOPMENT

- Vapor Phase Catalytic Ammonia Removal (In-House)
- Hydrogen Peroxide Boosted Aqueous Phase Catalytic Oxidation (SBIR Phase II)
- Direct Osmotic Concentration (SBIR Phase II)

RESEARCH

- Advanced Catalyst Development (In-House)
- Aqueous Phase Ammonia Removal System (SBIR Phase I)
- Oxidation Resistant Catalyst Supports (SBIR & In-House)

Focused Research Areas

Water Recovery Systems - Long Term Research

Integrated Systems (Bio-P/C)

OBJECTIVES

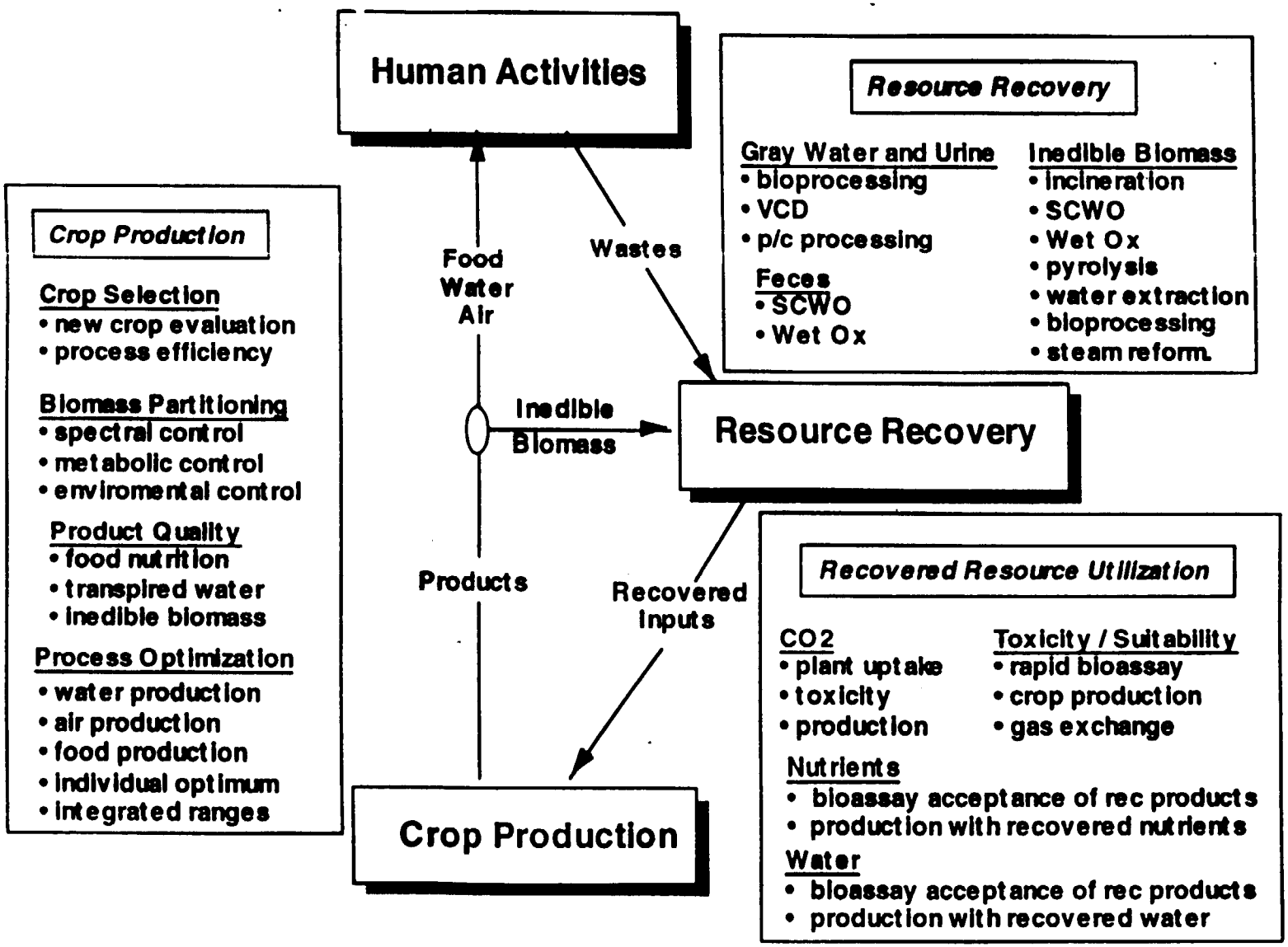
- **Define the level and method of pre and post treatment required to facilitate the utilization of human aqueous wastes in a plant based waste treatment system.**
- **Plants provide the capability of purifying water through:**

Filtration -	Roots act as particulate filters
Aerobic Bioreaction -	Roots provide surface area for microbial activity
Distillation -	Through the process of transpiration
Selective adsorption -	Through active transport across root membranes and selective partitioning in the roots and leaves.

APPROACH

- **Determine suitability of pre and untreated wastes as feed to a plant system.**
- **Determine purity of transpired water generated from such a plant based system.**
- **Determine the suitability of biomass produced in such a system for human consumption.**

CELSS Research and Technology Development Program



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Modeling, Analysis, and Control

OBJECTIVES

- **Conduct research on closed regenerative life support system design issues**
  - Subsystem definition/interfaces
  - Processor sizing and buffer volume
  - Hierarchical control system design
  - System dynamics
  - Long term stability
- **Validate theory and simulation using systems research laboratory hardware**

Modeling and Analysis

OBJECTIVE

- Develop a mission planning simulation tool and timeline for the Bio-PLEX

STATUS

- Candidate crop cycles were scheduled
- An algebraic method predicted and avoided harvest date conflicts
- Reported on food quantities and food processing steps and times

NEXT

- Expand schedules to include food processing, incineration other activities
- Investigate additional commercial scheduling software options
- Apply Operations Research and Artificial Intelligence scheduling techniques
- Define form and purpose of ultimate planning tool

Modeling and Analysis

OBJECTIVE

- Develop an overall biomass production model for the Bio-PLEX

STATUS

- Draft bibliographies on modeling and simulation and plant data
- Reviewed existing wheat model and Lab-Scale CELSS systems simulation
- Obtained list of desirable features of models from JSC

NEXT

- Collect data on the various crops to be used in Bio-PLEX
- Gather previous closed system crop models
- Develop sample partial models
- Identify needed data.

Controls

OBJECTIVE

- **Define the Bio-PLEX real time control system**
- **Define and implement agreed-on controls tasks.**

STATUS

- **Proposal to ARC Director to transfer AI technology to JSC**
- **Collaboration with an NRA-funded bioreactor project initiated to transfer this technology to ALS**
- **Development of a robust controller for an O_2 generation/removal system using higher plants and new oxide technology in progress.**

NEXT

- **Develop mathematical model of O_2 separation subsystem for control dynamics purposes**
- **Further task and collaboration definition**